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ULTRASONIC INSPECTION OF A GRAPHITE/EPOXY STRUCTURAL MEMBER USI--ETC(U)
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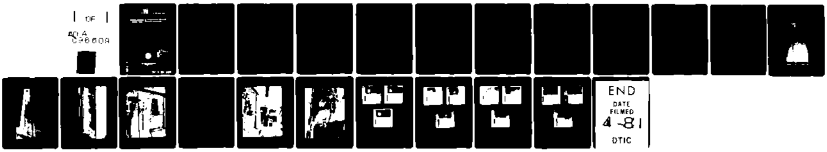

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Structural members, serving as models of a foil support strut for hydrofoil craft, have been built using graphite/epoxy material. A nondestructive evaluation (NDE) test is required to measure delamination (ply separation) as well as delamination growth which may occur during the structural fatigue testing cycle. This report describes the results of the first test sequence, using a ultrasonic thickness imaging instrument to accomplish the required NDE. These results support the contention that the ultrasonic thickness imaging device may be used to measure delamination growth in graphite/epoxy composites.

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CONTENTS

ULTRASONIC INSPECTION OF A GRAPHITE/EPOXY STRUCTURAL MEMBER USING A THICKNESS-IMAGING DEVICE

BACKGROUND

As part of a materials research project, the Navy is having built structural members using graphite/epoxy material. This part, called a Box Beam, is intended to model a foil support member for a hydrofoil craft. The David W. Taylor Naval Ship Research and Development Center (DTNSRDC) has been instrumental in the design and development of the Box Beam [1]. Among the tests to which this structure will be subjected are static load, fatigue and corrosion fatigue. In order to ascertain if damage has occurred during these tests, nondestructive evaluation (NDE) is required. NRL was called upon to find some means of detecting damage, as well as damage growth, which may occur during the structural testing cycle.

A separate research program, sponsored by NAVSEA's SSBN Ship Systems Maintenance, Monitoring and Support Office (SMMSO), has led to the development of an ultrasonic thickness imaging system [2,3]. This device was specifically designed to measure, non-invasively, degradation to the seawater system components within a submarine. As designed for the Navy, the Sea Water Component Measuring Instrument (SCIMI*) is currently being evaluated at selected shipyards. A host microprocessor controls data input and monitors all instrument settings. NRL has been the technical monitor and advisor for this project since its inception in 1976.

It was noted that the principal features of the SCIMI instrument would also fulfill the requirements for the Box Beam inspection. After obtaining permission to use the equipment from SMMSO, a

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*A commercial version of this device, developed by General Dynamics, Electric Boat Division's NDT Technology Development Group, is to be marketed under the trade name "Ultra Image."

contract was issued to Electric Boat Division to perform a baseline test. The results of this test are detailed in this report.

INTRODUCTION

The nondestructive inspection of composites is dependent upon both materials and structural characteristics. For graphite/epoxy systems, the acoustic properties of the components are similar. This material, therefore, provides a relatively low "background noise" environment for the NDE test. Furthermore, the structural design of the Box Beam member is such that the principal "flaw types" are interply delaminations, disbonds to attachments and gross microvoid contamination, thus simplifying the inspection requirements.

Ultrasonic inspection of bond quality is currently problematic. With respect to the Box Beam this problem is alleviated by using countersunk screws to partially transfer the load from the composite to the metal skeleton. Therefore, bond inspection is reduced to locating areas of total unbond. The only region where a bond problem currently exists is in the "scarf-joint" area. This is the transition zone where the composite material is beveled down to the steel support member (see Fig. 3).

Gross microvoid contamination is detected by monitoring ultrasonic transmission losses (attenuation due to scattering by the microvoids). Currently the graphite/epoxy panels are inspected, prior to assembly, for microvoid contamination. An immersion test is used to measure transmission loss as compared to a reference standard. This relatively simple test is sufficient to verify that, during the curing procedure, outgassing of the epoxy occurred properly and no large areas of microvoids exist.

The inspection of interply delaminations is discussed in the rest of the text. A delamination refers to a real separation between plies of the graphite tape. Of interest is the detection and measurement of delaminations that are one-quarter inch in diameter and larger. In addition any growth of these areas must be measured. For this test series the Box Beam was first inspected manually using conventional contact ultrasonics. Sites of delamination were noted and then inspected using the SCIMI equip-

ment. Three inspections for each site were done. After each set of inspections the structure was loaded to a rather low stress level. This loading sequence seemed to validate that baseline delamination measurements can be made without variation.

The Box Beam Structure

The Box Beam (Figs. 1 and 2) consists of a skeletal steel structure with graphite/epoxy face members, bonded and attached with countersunk bolts. The base is configured so that it may be bolted to the structural test stand. A hole, near the top of the tapered structure, is for attachment of the hydraulic ram used to apply the loads. The composite skin is 12.2 mm thick (0.48 in) constructed by laying up 85 plies, in various orientations, each 0.14 mm thick. Shown in Fig. 3 is a closeup of the scarf-joint region. This is the region where the graphite/epoxy is reduced in thickness and is bonded to the steel member.

The structure is to be tested in static, fatigue, and corrosion fatigue cycles. This portion of the work, as well as the design considerations of the structure, is detailed in Refs. 1, 4, and 5. Nondestructive inspection is to occur at various stages. The structure is first inspected manually to locate delaminated areas. These sites are then re-examined using the SCIMI instrument. Later the Box Beam will be subjected to larger loads, where damage may occur. Re-inspection will then be done and a comparison made to the baseline tests in order to measure delamination growth. To verify that the SCIMI equipment can make measurements of delamination consistently, a series of three tests were carried out. Sites were first chosen from the information determined via the hand scan tests. These sites were then inspected using the SCIMI equipment. The Box Beam was then subjected to a low load cycle and re-examined ultrasonically. This sequence was repeated in order to produce three inspection scans per site.

The SCIMI System

The SCIMI instrument is basically a thickness measuring and recording instrument. As presently configured, the scanner covers a 50 mm × 100 mm area (2" x 4") in 0.5 mm squares (0.020"). For

each square scanned, the thickness measurement taken at that point is stored in the computer memory. The echo amplitude is similarily recorded. A total of 40,000 depth as well as 40,000 amplitude information bytes is stored for each 2" × 4" area scanned. This high density information recording capability is the foundation for the subsequent formation of a thickness image profile. The depth resolution for the instrument is ±0.05 mm (0.002") in steel over a 12.5 mm (0.5") depth range. All ultrasonic instrument controls are monitored by the microprocessor. During the scanning cycle, the microprocessor also performs numerous diagnostic procedures to ensure that the data recorded falls within the prescribed limits. A more detailed description of this instrument is available in Ref. 3.

Test Set-Up

The Box Beam was set-up in the test frame as shown in Fig. 4. A hydraulic ram was attached to the top of the beam, providing the means of applying the required loads. Grid marks drawn and numbered on the graphite/epoxy faces served as site references. Nine areas were selected to be inspected by the SCIMI instrument; shown in Fig. 5. These areas were chosen as a result of the hand scan previously done. Each area had a known delamination. In addition a few problem areas, such as beveled bolt heads and thinning walls at the scarf joint, were included in the scanning sites.

The test set-up of the SCIMI system is shown in Fig. 6. A close-up of the scanner portion is shown in Fig. 7. A total of nine test areas on both the front and back faces of the Box Beam were inspected. The first series of scans provided baseline data. The next two series were taken after the beams were stressed to a low load. No major failures were expected and none were found in the areas selected to be monitored.

Table 1 is a print out of the input data to the SCIMI instrument prior to making a scan. This is the header information which is required to set up and run a scan. It was designed specifically for the submarine sea water piping inspection and used without alteration for the Box Beam inspection. Those items not relevant were bypassed for this test series. Item 2 refers to the grid number which was scanned (see Fig. 5). Items 9 through 13 describe the transducer and reference block used to set up

the instrument. The rest of the information, numbers 14 to 20 and 21 to 36, contains data relating to the scanner mechanism and the pulser/receiver. After the initial set up, subsequent scans were run using the same settings. In fact, a portion of the instrument's diagnostic routine is geared to ensure that, for comparative tests, the identical instrument set-up is used.

Results

Shown in Fig. 8 (a,b,c) are the images created by the SCIMI instrument. Information concerning the mapping parameters is shown in Table 2. The letters a, b, c, in Fig. 8 represent the three scans taken; (a) is the baseline scan and (b) and (c) are the subsequent scans after each loading cycle. A dark circle on the left side is the area where the bolt was located. The white region is the delaminated area, with a black cross marking the region where depth and location information is to be analyzed. Shown on the upper left are the x and y reference locations and the number, 0.220, is the depth of the delamination in inches. On the lower portion of the image is a depth scale along the x axis depicting the 5 scale grey levels taken from the cursor location. As can be seen, the images of the delamination are remarkably similar, even though the three scans were not physically started at identical locations.

Figure 9 (a,b,c) shows the information from site 120. Not all of the 50 x 100 mm scan area was used for the image. Again a bolt hole is outlined and two delaminations are seen around it. A third larger delamination is seen at the edge of the beam. Figure 10 (a,b,c) is the image of the site just below to the scarf-joint transition. Numerous small "delaminations" can be seen, as well as several larger ones. The lower right dark area is a site not accessible for scanning. This set does not repeat as well as the previous ones. In part this is due to a small amplitude variability which exists in the instrument. Most delaminations produce a strong echo and are readily imaged. When the return signal is small, the recorded amplitude may fall on either side of the displayed threshold. For our current needs this does not appear to be a problem. The last set, Fig. 11, is the image from the bottom of area 9. Here the scan is in the scarf joint region and reflection signals from various interfaces abound. Figs. 11a and 11b represent two scans taken at slightly different gain settings. Fig. 11c is a repeat of 11b but

displayed using a different threshold and grey scale. Viewed under these conditions, the horizontal line near the top of the scan represents the transition at the scarf joint.

Commentary

The evidence thus far on hand supports the contention that the SCIMI instrument may be used to measure delamination growth in graphite/epoxy composites. The capability of creating a stable image, paramount in order to show delamination growth, has been verified in this test series. There are other inherent capabilities in this instrument, which may allow for a rudimentary bond inspection of the scarf joint region. Currently there are no plans to pursue this area. A follow-up test is planned of another Box Beam which is scheduled to incur damaging loads. The SCIMI instrument will be used for this test series.

Acknowledgments

Technical support from the following individuals have made this project possible and fruitful: Maureen Barry, Project Manager for the Box Beam, Naval Ship Research and Development Center, Carderock, Maryland; Robert H. Grills and Dean E. Christie, General Dynamics/Electric Boat Division. This project is sponsored by the Naval Sea Systems Command, Project Number SF54-591-501, Dr. H. H. Vanderveldt, Program Manager.

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1. Couch, W.P., "Advanced Composite Box Beam, Laboratory Evaluation and Technology Assessment Plan," DTNSRDC Technical Memorandum M-82, September 1977.

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3. Grills, R.H. and Nicholas, J.R., Jr., "SCIMI - A Microprocessor Based Ultrasonic Imaging System," Paper Summaries, 39th ASNT Fall Conference, October 1979, pp. 175-189.

4. Greszczuk, L.B. and Ashizawa, M., "Advanced Composite Foil Test Component (Tapered Box Beam)," McDonnell-Douglas Astronautics Company, Final Report MDC-G7596, May 1977.

5. Greszczuk, L.B. and Couch, W.P., "Design Fabrication, and Nondestructive Evaluation of an Advanced Composite Foil Test Component (Tapered Box Beam)," ASTM Special Technical Publication (STP 674), 1979, pp. 84-100.

Table 1 — Header Information

1	BOAT NUMBER	=	NRL	19	HOLE PXL HI LIMIT	=	25
2	SMMSO ID CODE	=	133	20	PREVIOUS AREA SCAN'D	=	0
3	TEST DATE	=	05 06 80	21	METROTEK PULSE AMPLI	=	100
4	TEST NUMBER	=	007	22	METROTEK PULSE DAMP	=	100
5	MRC NUMBER	=	A	23	METROTEK PULSE WIDTH	=	LOW
6	MRC DATE	=	0	24	METROTEK FILTER	=	4
7	INSPECTOR NUMBER	=	46004	25	METROTEK RF DET SGNL	=	ON
8	EQUIPMENT ID CODE	=	002	26	METROTEK RANGE SELCT	=	4
9	XDCR SERIAL NUMBER	=	0768	27	METROTEK DELAY	=	2 4
10	CAL. BLOCK ID	=	EPOX	28	METROTEK GATE	=	8 0
11	CAL. BLOCK THICK.	=	404	29	METROTEK ATTN THEO.	=	16
12	MATERIAL COMPOSITION	=	EPOX	30 **	METROTEK ATTN ACTUAL	=	0
13	NOMINAL THICK	=	400	31	THRESHOLD SETTING	=	80
14	ALERT NUMBER	=	0	32	VELOCITY CONST THEO.	=	132
15	SCANNER X SCALE FCTR	=	141	33 **	VELOCITY CONST ACT	=	140
16	SCANNER Y SCALE FCTR	=	141	34	HOLE DEPTH LIMIT LO	=	4
17	SCANNER OFFSET	=	0	35	HOLE DEPTH LIMIT HI	=	42
18	HOLE PXL LOW LIMIT	=	9	36	CAL. DESIGNATOR	=	1

Table 2 — Mapping Information

MAPPING PARAMETERS

SCAN NUMBER	-	0
DEPTH DATA		
RANGE	-	4 MILS/BIT
NOMINAL THICKNESS	-	.5 INCHES
VIEWING THRESHOLD	-	.5 INCHES
STEP	-	20 %

Enter 'CR' when ready. ?

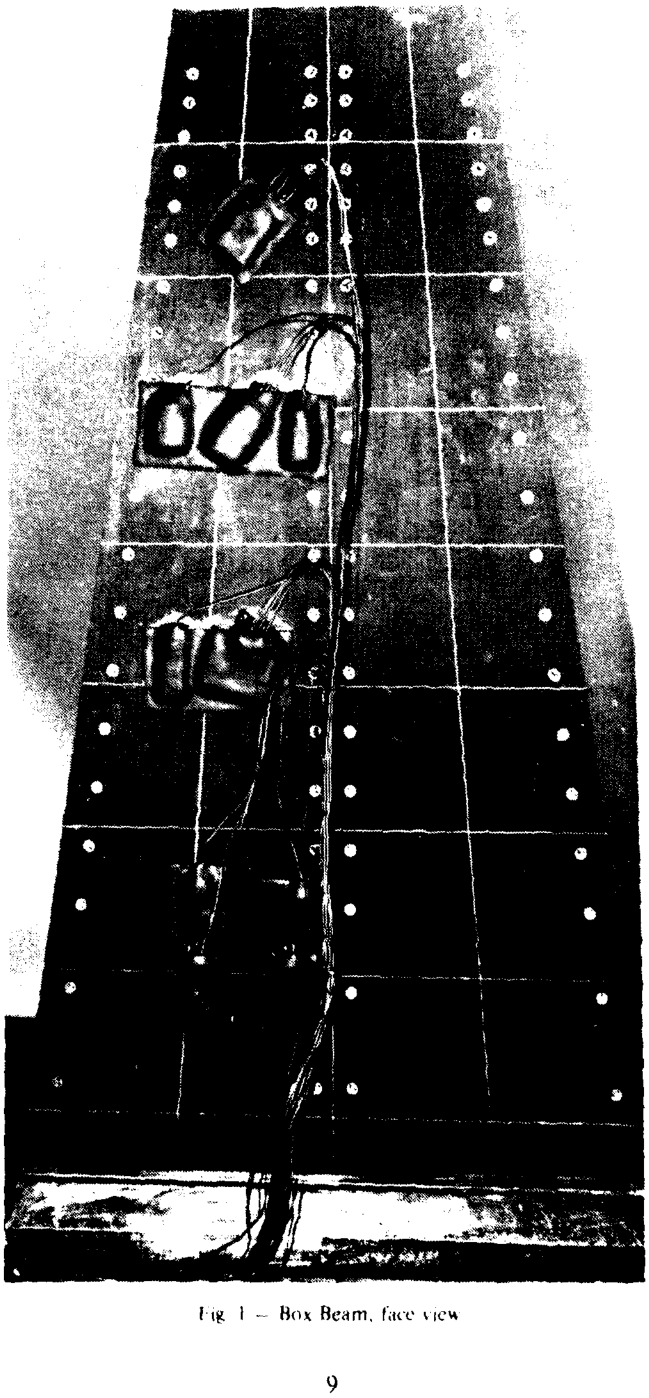


Fig. 1 — Box Beam, face view

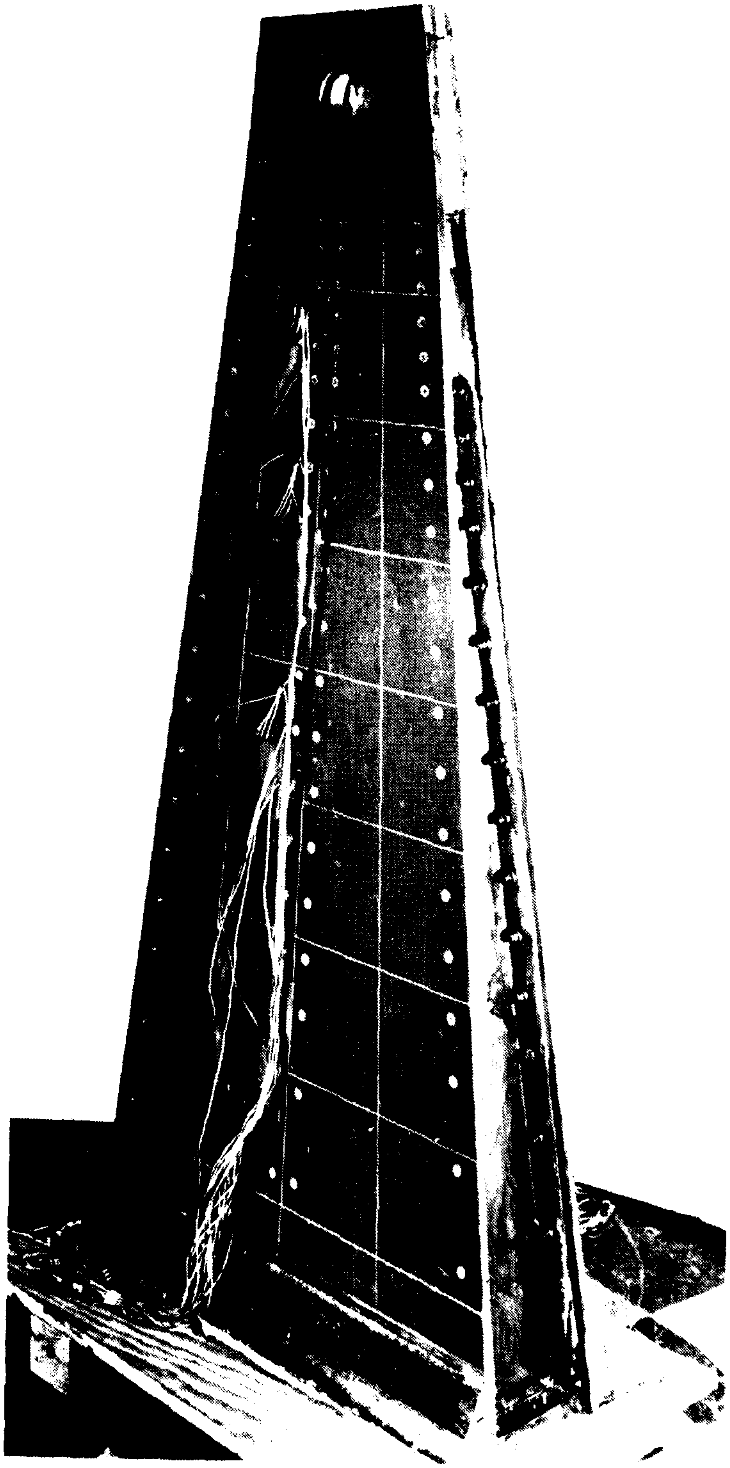


Fig. 2 — Side view of Box Beam

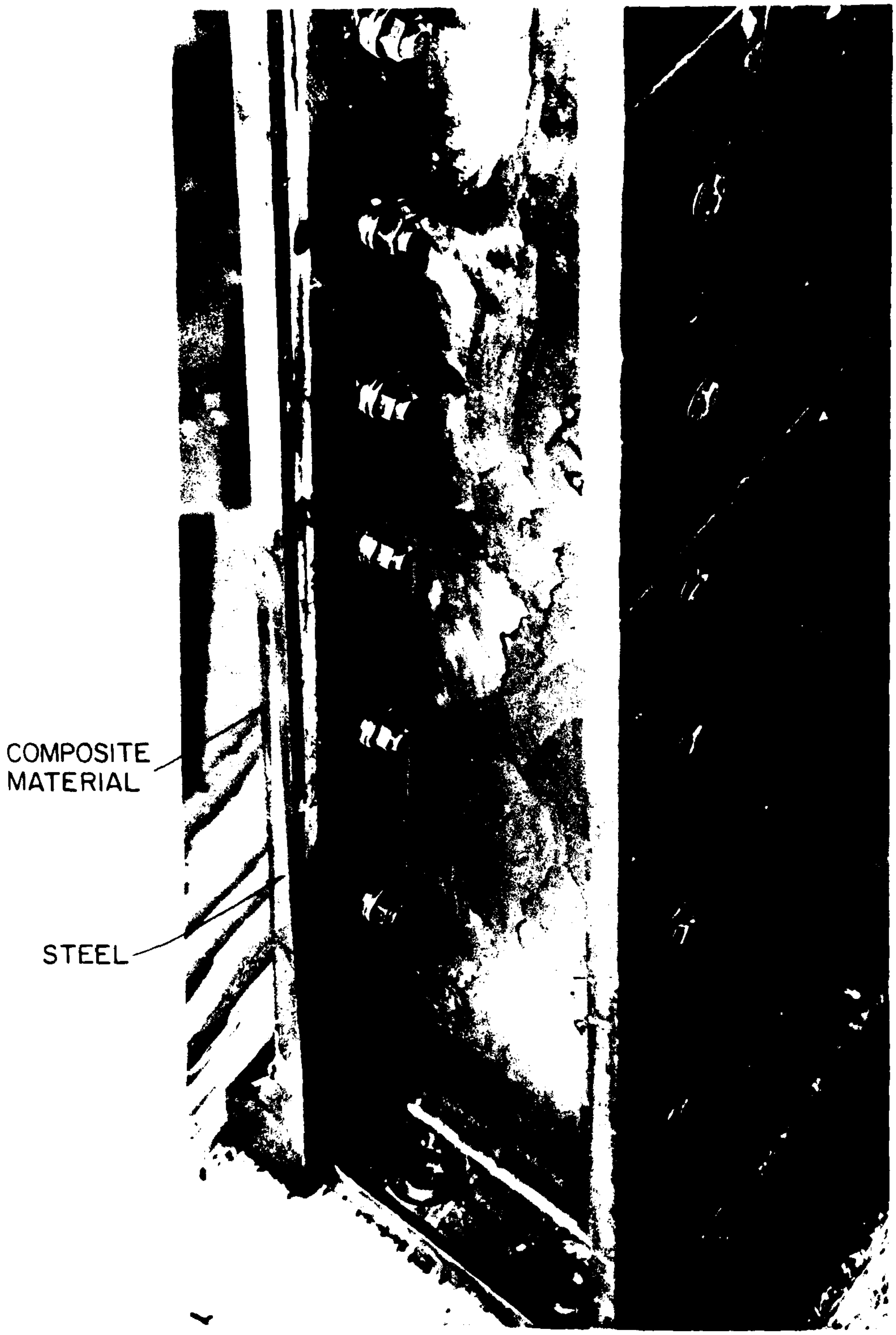


Fig. 3 — Close up of scarf joint. The beveled steel and composite sections make ultrasonic inspection quite difficult

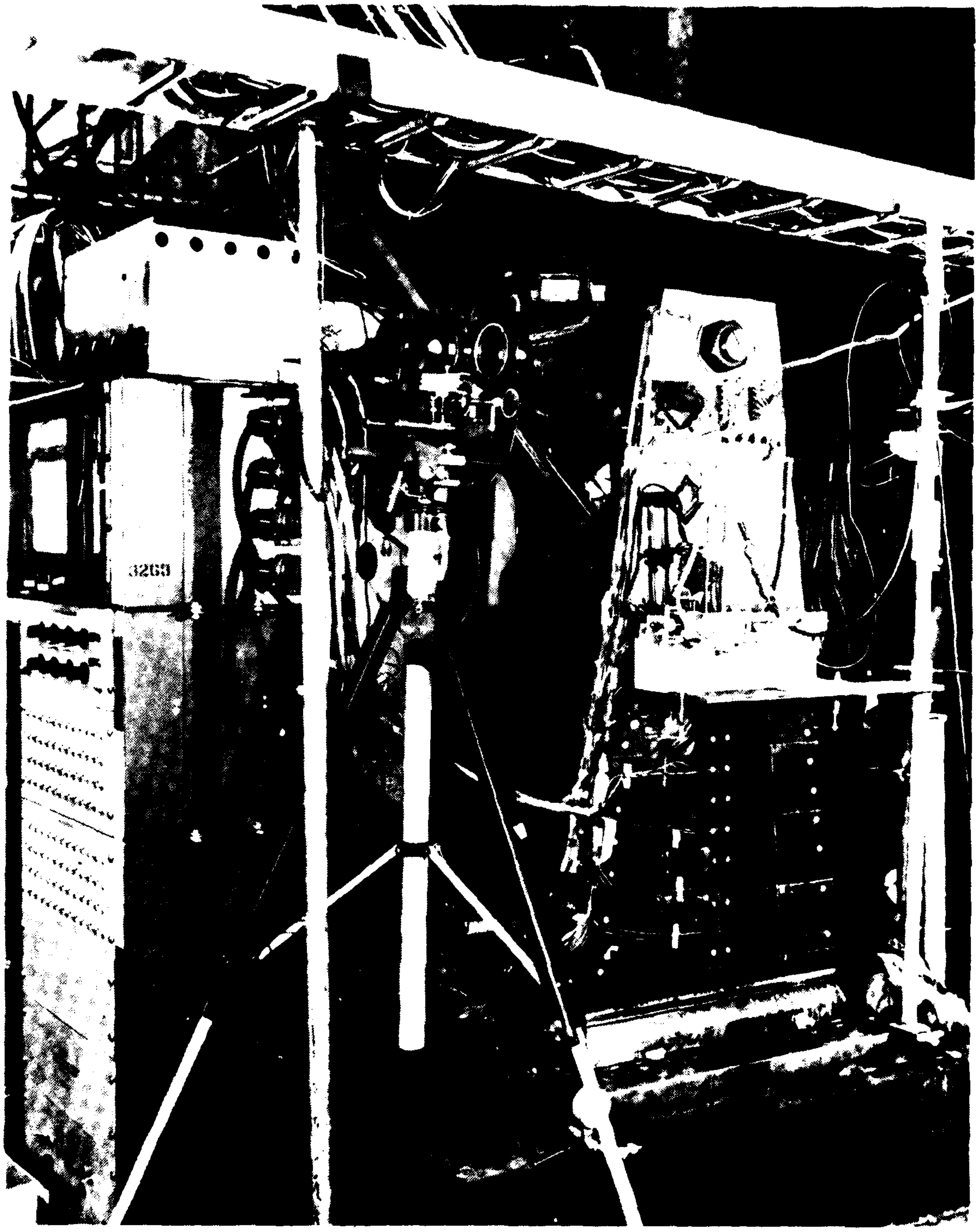


Fig. 4 — Box Beam in test frame

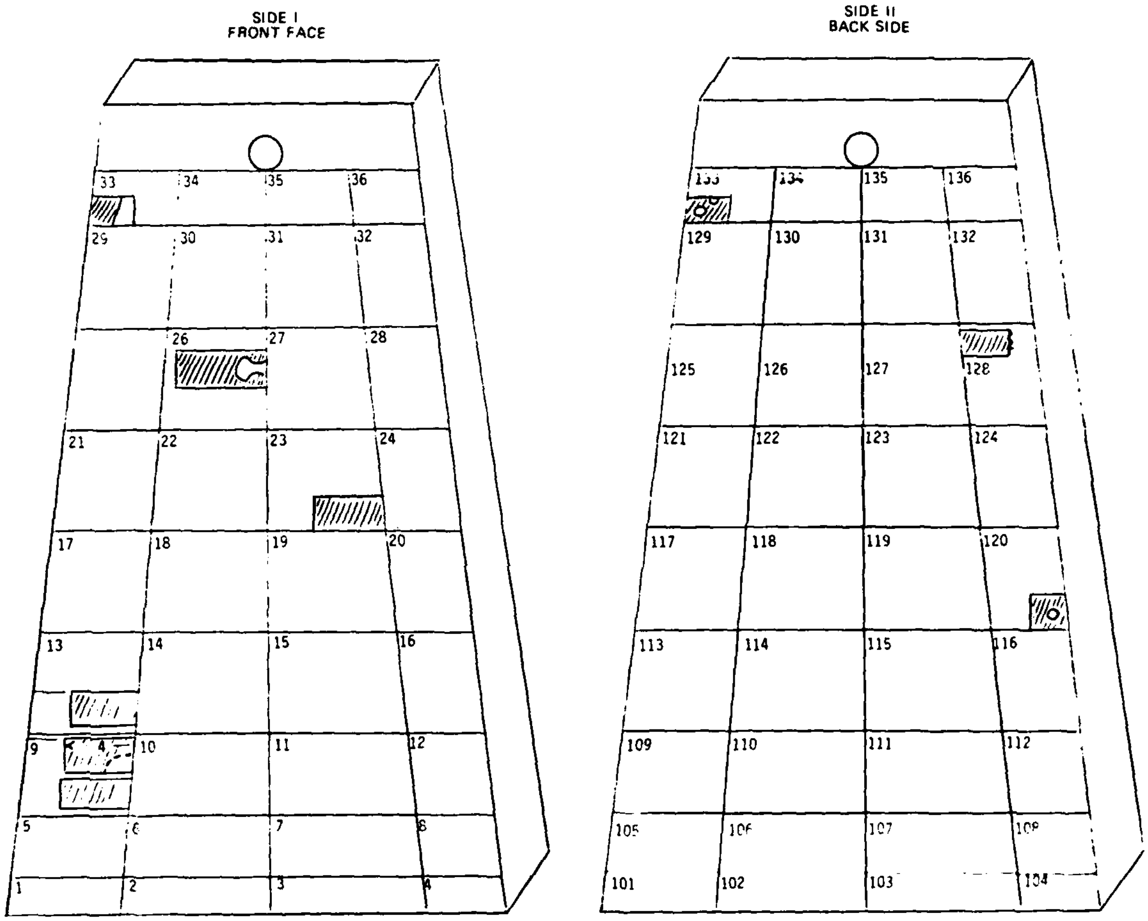


Fig. 5 — Grid sections drawn on the composite faces. The shaded areas are those sites chosen for the SCIMI inspection.

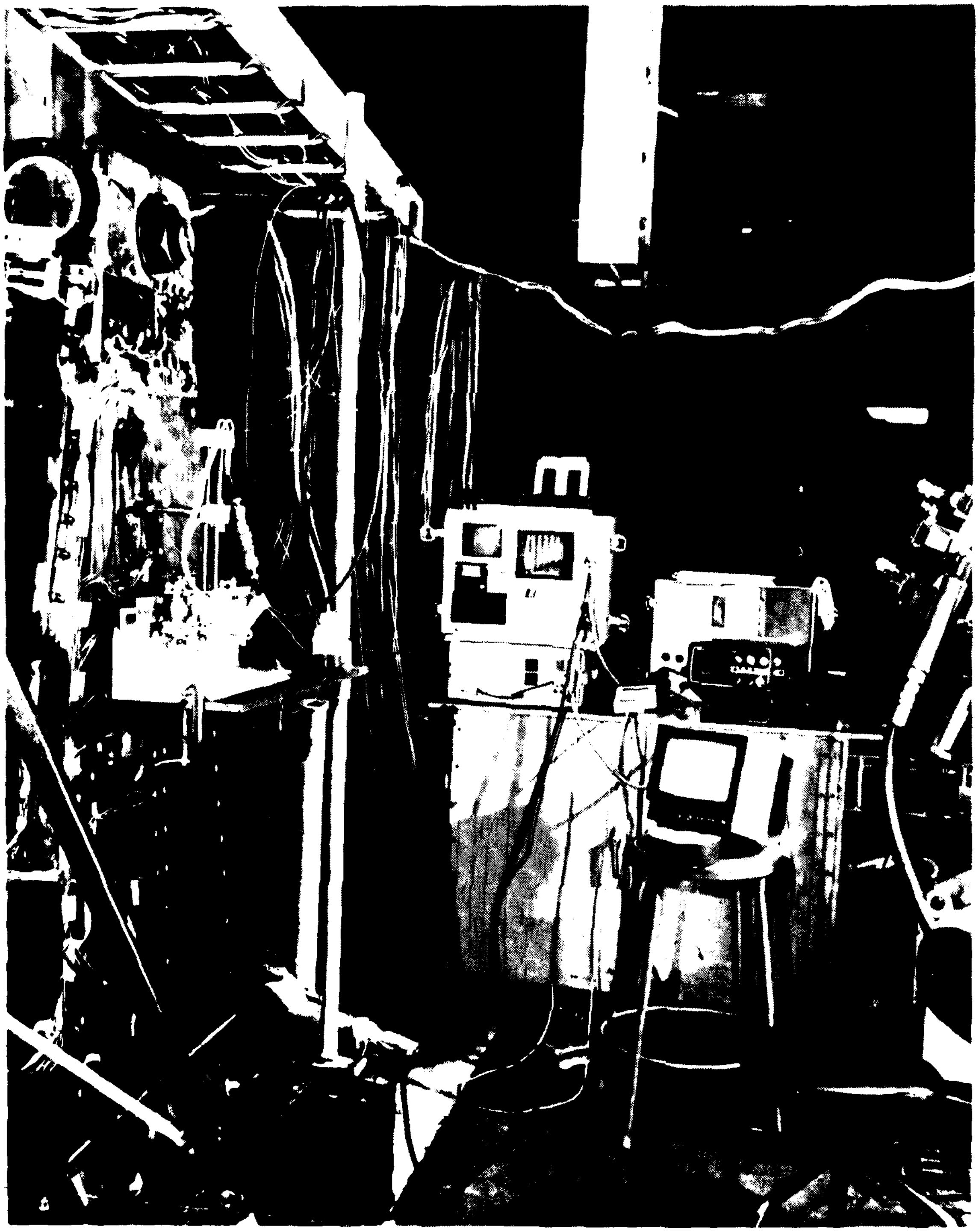


Fig. 6 — The SCIMI instrument

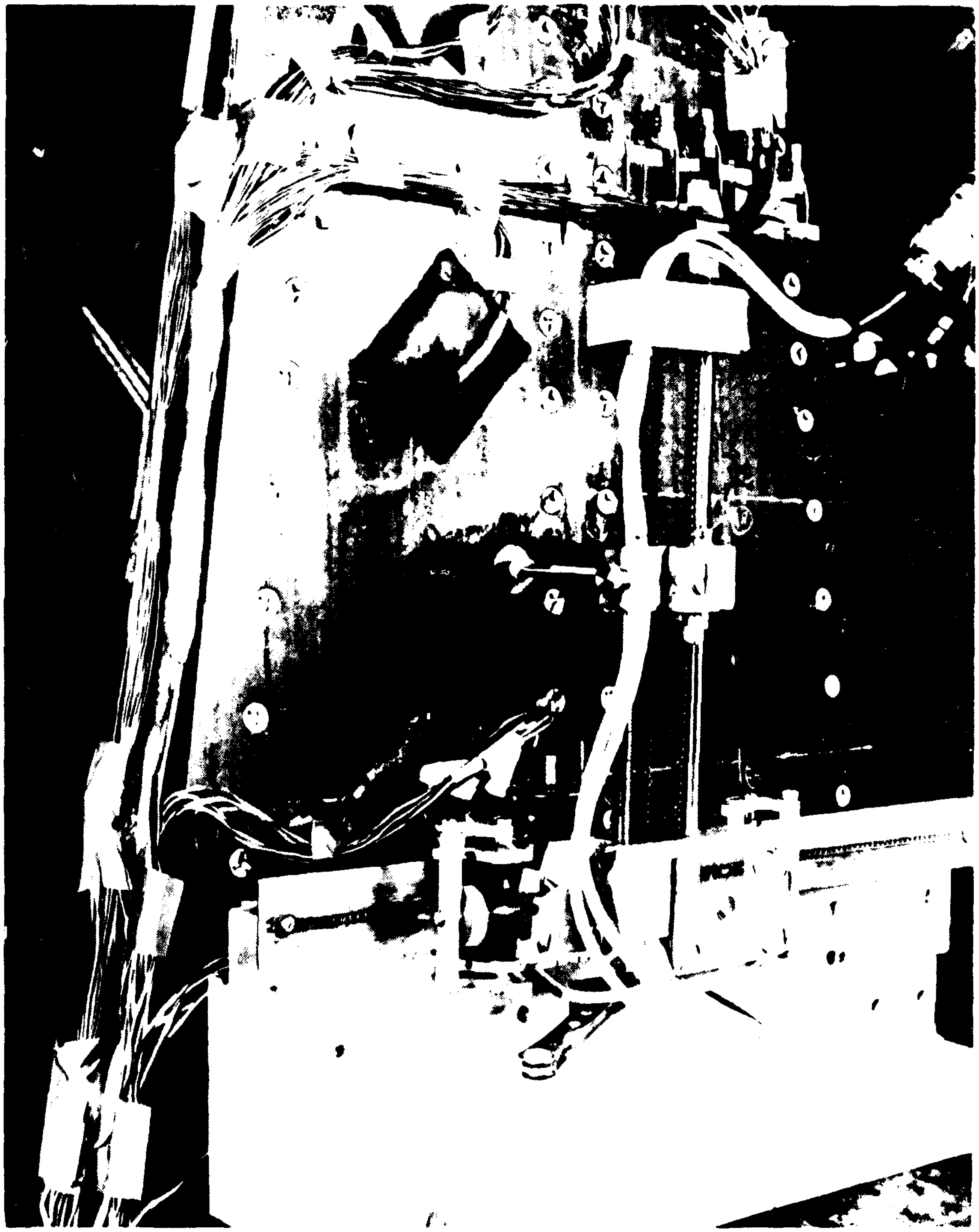
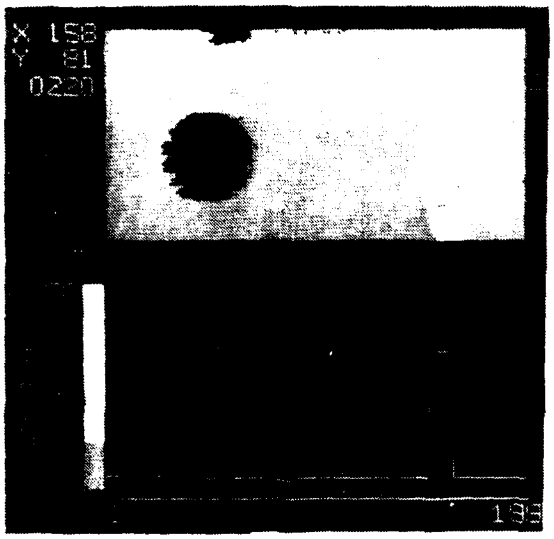


Fig. 7 — Close-up of the scanner mechanism



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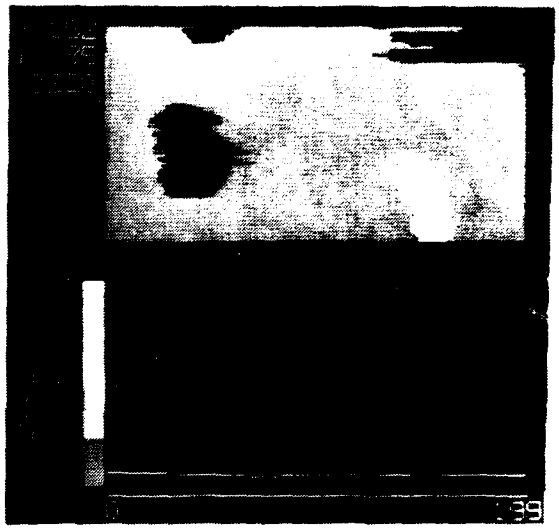

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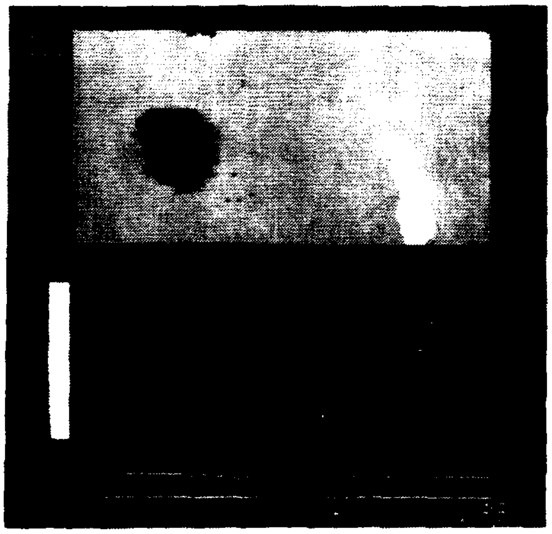
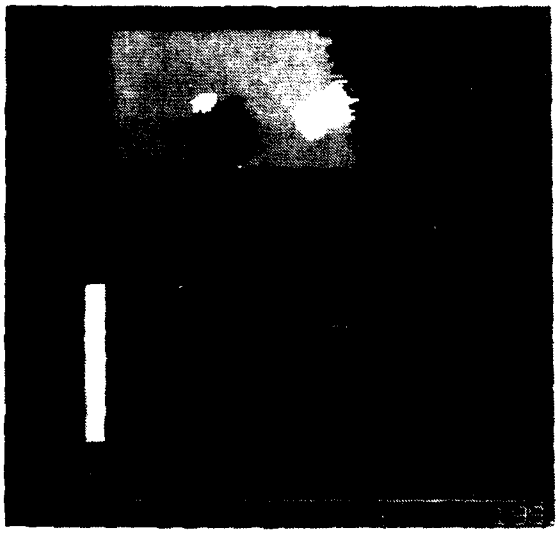


(c)

Fig. 8 — Three scans from site 133



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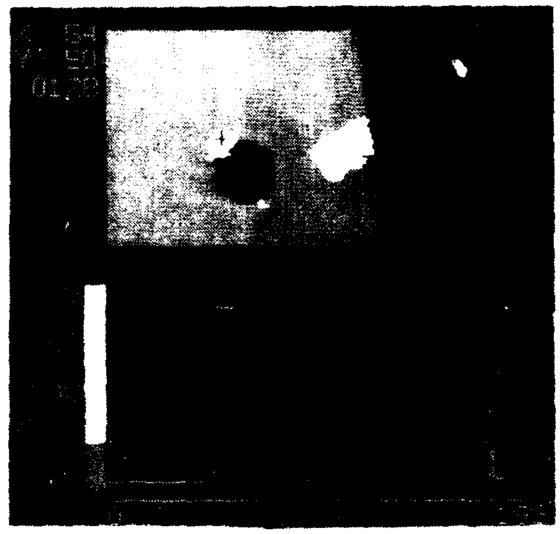

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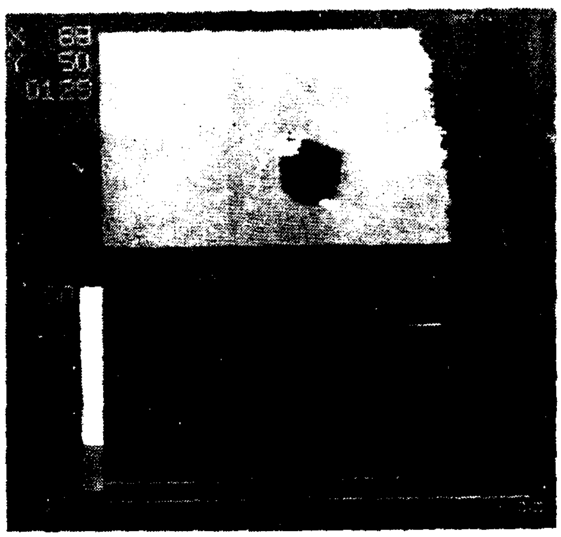
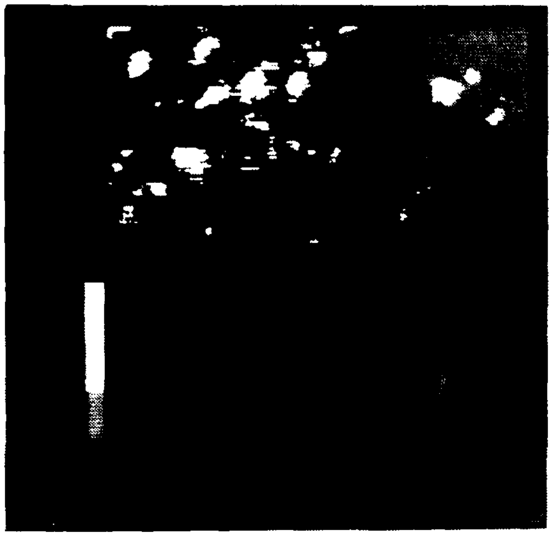


(c)

Fig. 9 — Three scans from [illegible]



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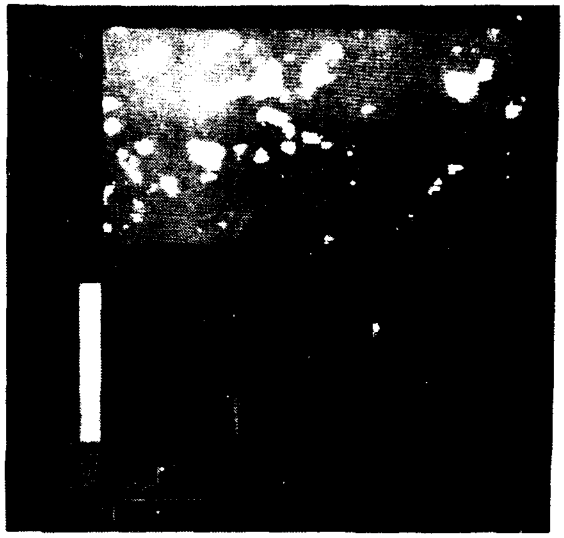
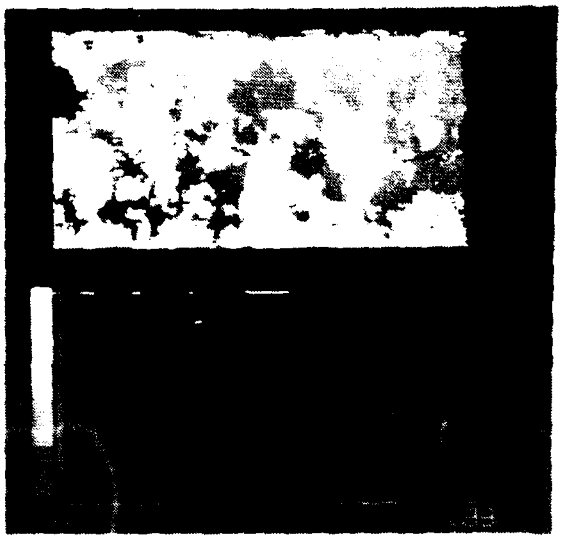


(b)

(c)

Fig. 10 — Three scans from site 91



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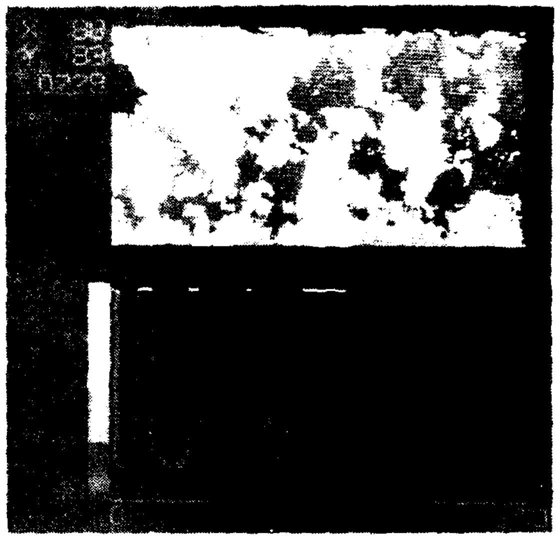

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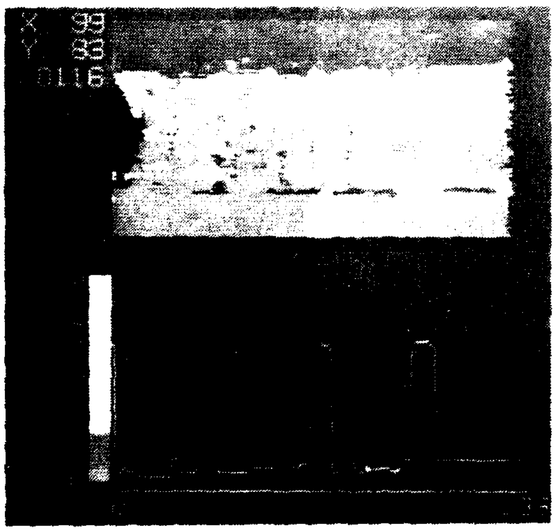

(c)

Fig. 11 — Three scans from site 9B

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